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Performance verification of focus variation and confocal microscopes measuring tilted ultra-fine surfaces

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Abstract

The behaviour of two optical instruments, scilicet a laser scanning confocal microscope and a focus-variation microscope, was investigated considering measurements of tilted surfaces. The measured samples were twelve steel artefacts for mould surface finish reference, covering Sa roughness parameter in the range (10^1—10^3) nm. The 3D surface texture parameters considered were Sa, Sq and Sdq. The small working distance of the confocal microscope objectives influenced the measurement setup, preventing from selecting a high tilting angle. The investigation was carried out comparing measurements of flat surfaces (0° tilt) with measurements of 12.5° tilted surfaces. The confocal microscope results showed a high sensitivity to tilting due to the laser beam reflection on the metal surfaces. The focus variation microscope results were more robust with respect to the considered angular variation, although they were out of the instrument operating range except for one of the twelve artefacts.

Introduction

Precision injection moulding requires high accuracy moulds, frequently having free-form surfaces. Optical metrology has an increasing key role in quality assurance of the precision injection moulding production, hence, a clear understanding about measurements of tilted surfaces is needed.

The flat surfaces of twelve steel cylindrical artefacts were measured by a laser scanning confocal microscope (CFM) and a focus-variation microscope (FVM), analysing the relative deviations of the surfaces measurements in one specified tilted position with respect to 0° tilt angle surfaces measurements. The roughness parameters chosen for the analysis were the arithmetic average height *Sa*, the root mean square height *Sq* and the root mean square gradient *Sdq*.

Examples of artefacts are shown in Fig. 1.

Measurement setup

Measurements were carried out in the centre of each artefact, performing five repeated acquisitions respectively at 0° and at 12.5° tilt angles. No stitching was used, therefore the field of view (FoV) of each raw acquisition was cut and resampled to the same number of pixels, in order to match the discretisation level of the acquired areas. Moreover, all measuring settings were kept the same in the two cases of tilting with the aim of detecting variations for the most due to the angled surfaces.

In the post-processing, SPIP™ was used to level, cut and resample the acquired surfaces. No filtering was applied. The small working distance of the CFM when using 50× and 100× objectives prevented the use of this lenses. In this case, a 20× (NA = 0.60) magnification lens was only used. Indeed, the 12.5° tilt angle was chosen because it was the highest one possible, considering the limited working distance of CFM (1 mm) with 20× objective. Figure 1 (b) shows the setup of one artefact on CFM.

The FVM provided correct results only when measuring the artefact with highest value of roughness. The main issue may be related to the fact that the resulting surfaces had local roughness that was too low to allow proper detection by FVM. The investigation of FVM was consequently carried out for one artefact, though extending it to 20× (NA = 0.40), 50× (NA = 0.55) and 100× (NA = 0.80) objective lenses. Their use was, in fact, allowed by a higher working distance.

Results

The relative deviations was calculated between measurements of flat surfeces, referred to 0°, and surfaces with 12.5° tilt angle.

The results provided by CFM showed a conspicuous increase of surface parameters values after tilting the surfaces. In particular, *Sa* deviations range between 13 % and 152 %, *Sq* deviations follow in the range between 18 % and 171 %, while *Sdq* reaches deviations between 76 % and 680 %. Averages of the relative deviations of the examined roughness parameters, for each of the twelve artefacts, are in the histogram of Fig. 2: *Sa* and *Sq*, largest deviations were observed with the artefacts *A1*, *A2*, *A3* and *A4* (smoothest ones – relative deviations around 100 %). A tendency to disturbances (spikes) increase was also observed (see an example of Fig. 3). This tendency to spikes significantly increased when considering artefacts *A10*, *A11* and *A12* (dry blasted artefacts). However, the amount of spikes was such to considerably produce relative deviations only with the artefacts *A11* and *A12* (roughest ones).

No specific trend was noticed for *Sdq* deviations, although they are slightly influenced by what observed for *Sa* and *Sq*.

As already stated, one artefact was evaluated by FVM, investigating the influence of tilting for the three objectives 20×, 50× and 100× magnifications. The results showed a low sensitivity to 12.5° tilt angle. In particular, relative deviations for the three parameters examined range between 4 % and 11 % among the three objectives, raising up to 20 % when considering *Sdq* measured with 50× magnification. Averages of the relative deviations of the examined roughness parameters are in the Histogram of Fig. 4. No disturbances due to tilting were detected, as shown in the example of Fig. 5.

Conclusions

The relative deviations between measurements of flat (0° tilt angle) and tilted surfaces (12.5° tilt angle) showed that CFM was extremely sensitive to the surface tilting, above all when considering the slope parameter *Sdq*. FVM was instead more robust when measuring tilted surfaces, provided it is used within its operating range. Nonetheless, accurate measurements of tilted surfaces may be achieved by CFM using a fixture to re-establish the orthogonality between the optical axis of the lens and the surface under evaluation. To this purpose, the so-called long working distance objectives are necessary.

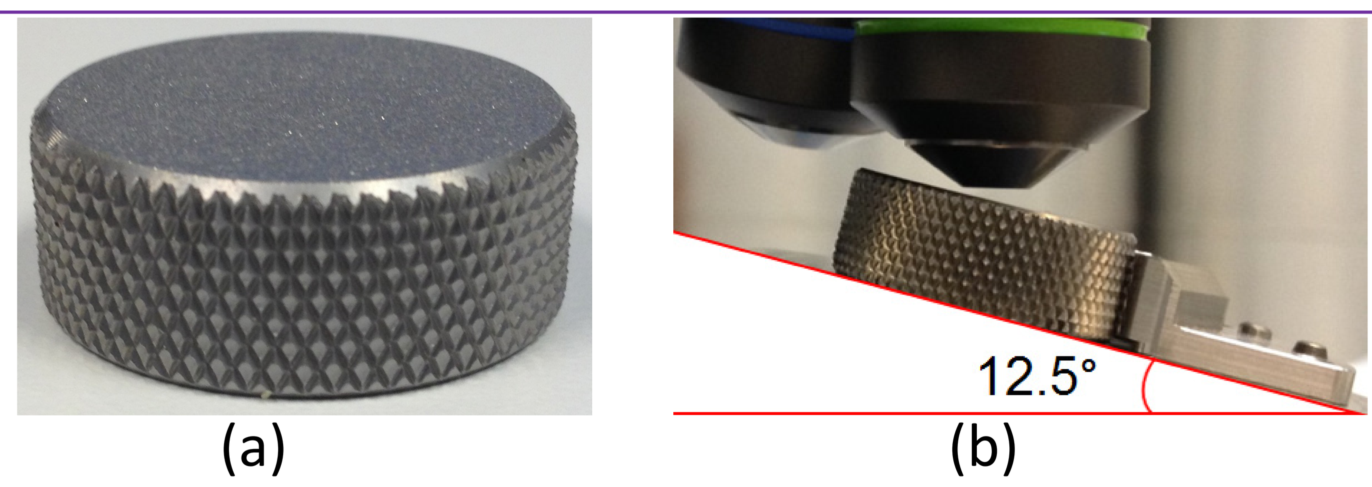

Figure 1. (a): example of cylindrical steel artefact (*A12* in Table 1). (b): experimental tilted setup of confocal microscope (20× magnification objective).

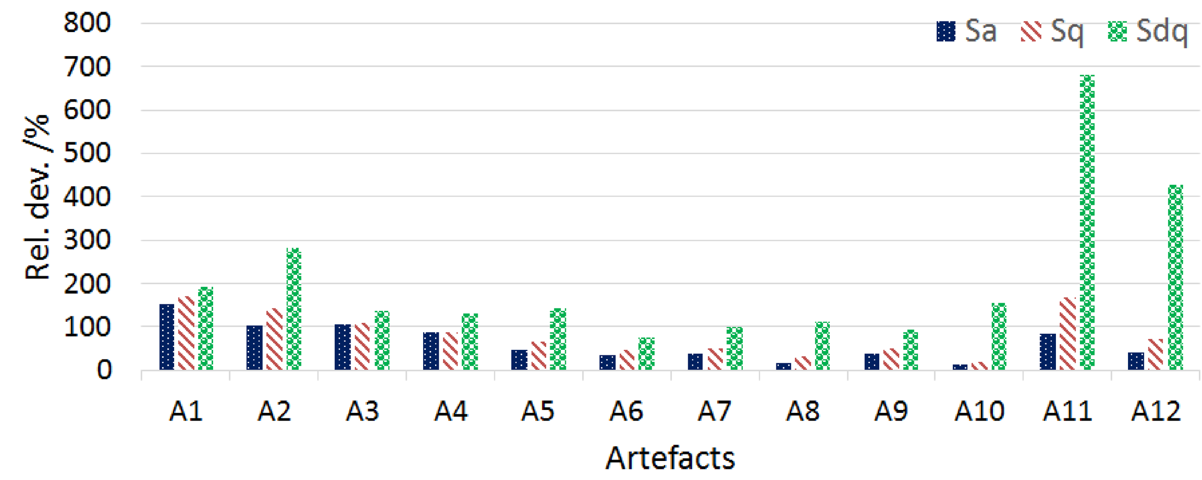

Figure 2. Relative deviations of *Sa*, *Sq* and *Sdq*, related to confocal microscope, for each of the twelve artefacts examined (20× magnification).

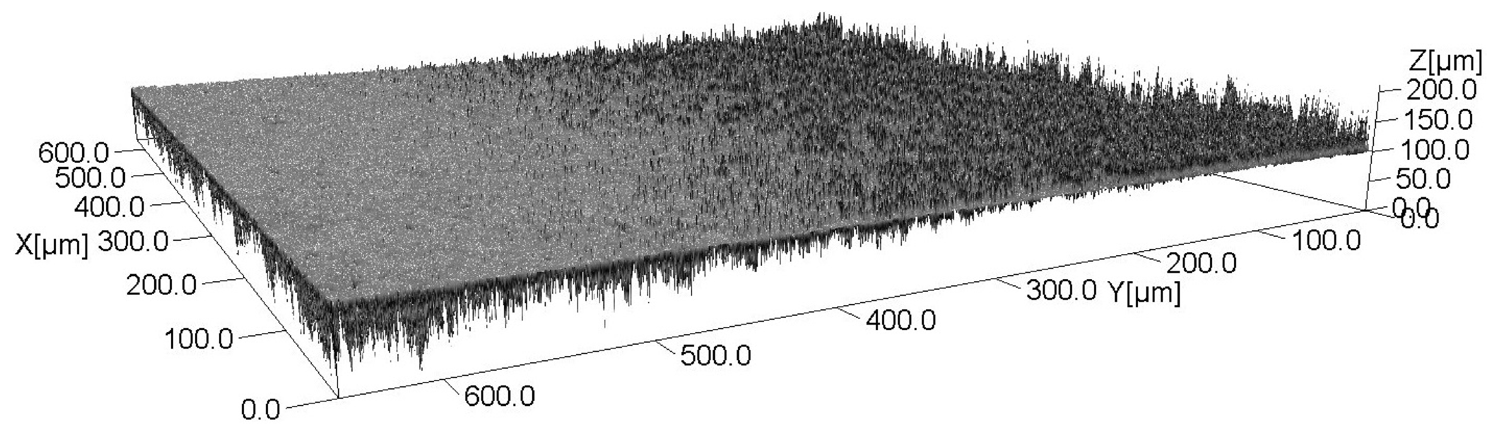

Figure 3. Example of tilted surface acquired by confocal microscope (artefact *A12* – 20× magnification, uncut field of view). Symmetrically spread spikes can be noticed.

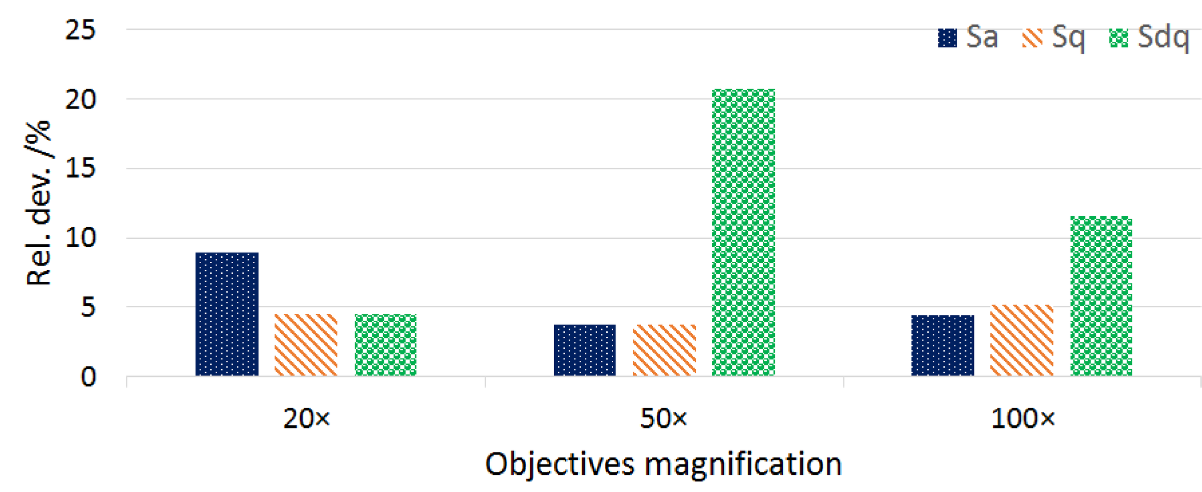

Figure 4. Relative deviations of *Sa*, *Sq* and *Sdq* related to focus-variation microscope (artefact *A12*).

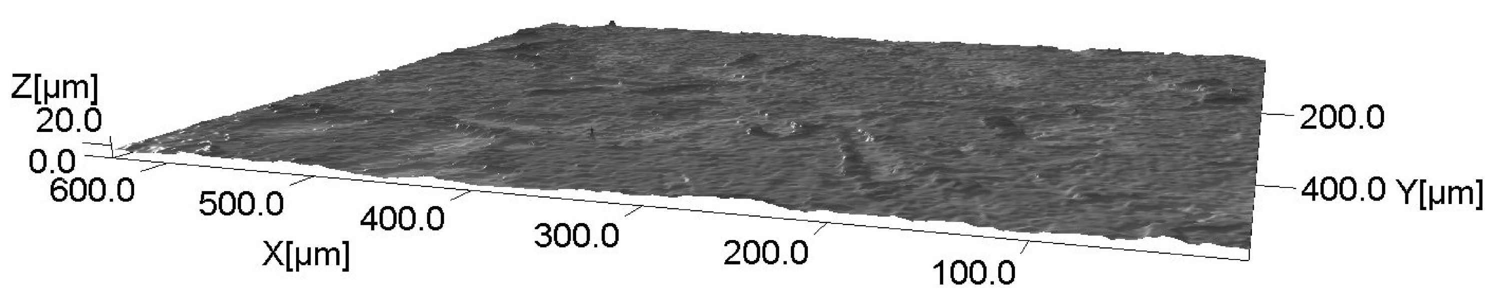

Figure 5. Example of tilted surface acquired by focus-variation microscope (artefact *A12* – 20× magnification, uncut field of view).

Table 1. Nominal *Ra* intervals and type of surface polishing of the reference artefacts.

Artefact	Machining	Nominal Ra interval /µm
A1		< 0.010 ÷ 0.025
A2	Diamond buff	0.025 ÷ 0.050
A3		0.050 ÷ 0.076
A4		0.050 ÷ 0.076
A5	Grit paper	0.100 ÷ 0.127
A6		0.229 ÷ 0.254
A7		0.254 ÷ 0.304
A8	Stone	0.635 ÷ 0.711
A9		0.965 ÷ 1.067
A10		0.254 ÷ 0.304
A11	Dry blast	0.660 ÷ 0.813
A12		4.826 ÷ 5.842

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